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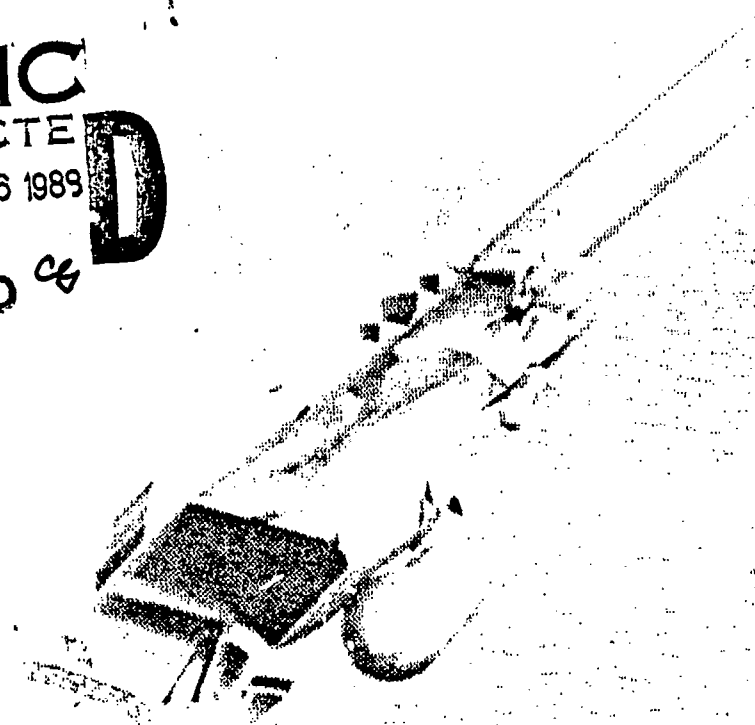
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COMPARISON BETWEEN THE LASER-BADAL AND VERNIER OPTOMETERS

Leonard A. Temme and William B. Cushman

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SUMMARY PAGE

THE PROBLEM

Night myopia is a refractive error that occurs in individuals in a dark or an empty but lighted visual field, even though the individuals are optimally corrected for far vision in a normally lighted field with contours. While the general population has, on the average, 1.0 to 2.0 diopters (D) of night myopia, the U.S. Navy fighter pilot has significantly less. The difference in night myopia between the pilots and the general population is so dramatic that refractive state in the dark may be an important factor for personnel selection or retention. It may also be an important aspect of vision that is affected by training and experience. Several methods are available for measuring the refractive state of the eye. The present paper compares the vernier optometer to the more widely used laser-Badal optometer. It also evaluates the vernier optometer as a practical screening instrument for routine measurement of night myopia in a sample of naive subjects drawn from a pool of student naval aviators (SNAs). We also measured dark vergence in the same sample of SNAs.

THE FINDINGS

There was no statistically significant difference found between the dark vergence of the SNAs and that reported in the literature for a sample of college students.

1. The vernier optometer was much easier, simpler, and quicker to use than the laser-Badal optometer.

2. The correlations between the test and retest measurements obtained with the vernier in the light and in the dark were 0.83 and 0.87, respectively.

3. The correlation between subject mean scores made with the vernier optometer in the light and in the dark was 0.92.

4. Measurements obtained in the dark with the two laser-Badal optometers resulted in test-retest correlations of 0.92 and 0.91.

5. Unambiguous data were obtained from every subject tested on the vernier optometer, whereas a number of subjects were not able to produce usable data with the laser-Badal optometer. This resulted in a subject selection, which may have inflated the test-retest reliabilities obtained with the laser optometer.

6. Experimental sophistication is required to operate the laser-Badal optometer, whereas the vernier optometer can be operated by a relatively inexperienced operator.

7. The difference between mean scores on the vernier and laser-Badal optometers was statistically significant, almost 3 D in some conditions. This large difference may have been due to a number of factors including limitations in the implementation of the principle of the vernier optometer and the small number of subjects measured on all instruments.

RECOMMENDATIONS

1. The vernier optometer should be improved and evaluated as a screening instrument and for studying the effects of pilot experience on night myopia.
2. The current Naval Aerospace Medical Research Laboratory's (NAMRL) vernier optometer should be rebuilt with better quality lenses, head stabilization, and a finer target.
3. The refined vernier optometer should be compared with the laser-Badal optometer to identify the sources of the observed differences in dark focus measured with the vernier optometer and the laser-Badal optometers.

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We wish to thank Dr. Robert Hennessy for the initial design of the vernier optometer, Mr. Ed Ricks for its construction and other essential technical support, and Dr. Jim Marsh for valuable discussion and advice on the calibration of these instruments.



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INTRODUCTION

Much of the research on the mechanisms of accommodation has conceptualized it as a negative feedback loop designed to minimize the error from an input signal (1). In the absence of an input signal or stimulus, the feedback loop is opened, and the state of the accommodative apparatus is determined by the internal biases of the network. Dark focus, the refractive state of the eye in the absence of a visual stimulus, is indicative of this internal bias, and for samples of college students is from 1.0 to 2.0 diopters (D) of myopia (2,3).

High positive correlations have been found among the laboratory measurements of dark focus of individuals, their refractive states at night, and in an empty but lighted visual field (2,4). In other words, individuals who may be adequately refracted for distance vision in a normally lighted and contoured environment may have significant amounts of myopia at night or in a field with few contours (2,5). Pilots routinely fly in conditions conducive to night and empty field myopias, a fact which has prompted investigation and discussion of the possible impact of these myopias on aviation (6-8,19).

One major issue is the identification of procedures and instrumentation that would simplify routine evaluation of dark focus in untrained observers. Such instrumentation would facilitate the evaluation of the importance of dark focus for: 1) preflight student pilots and their subsequent success in aviation, and 2) experienced pilots and their aviation performance. A major step in this direction has been the development of the laser-Badal optometer (LO), a relatively inexpensive and uncomplicated apparatus (4,9). Most measurements of dark focus reported in the literature have been made with this type of optometer.

Two LOs were constructed at NAMRL. One was used in a vision test battery administered to fighter pilots at the Tactical Air Combat Training range, Oceana, Virginia. The tests showed that dark focus of fighter pilots is significantly and dramatically different from that reported for college students (2,8,14,15). On the average, pilots have about 0.40 D of myopia whereas students have from 1.0 to 2.0 D. The possibility exists that dark focus may be an important factor for aviation personnel selection, retention, and training.

While conducting these studies, we found the LOs had a number of shortcomings. For example, some individuals had difficulty making the visual discriminations required by the test. Of the 172 pilots we tested, about 10% were not able to respond systematically to the stimulus pattern. The time required to administer the test depends on the ability of the subject to make the discriminations; about 15 to 30 min were required to test each subject. Substantial experimental sophistication and training are required of the test administrator. These factors limit the usefulness of the LO as an instrument for routine screening purposes.

A more recently developed optometer, the Vernier Optometer (VO), uses crossed polaroids (10) and may be a better screening instrument than the LO (8,11). The VO requires the subject to discriminate the alignment of two

lines, which is a far easier task than that required of the LO. Furthermore, the optics and general construction of the VO are much simpler and less expensive than those of the LO.

A prototype VO was constructed at NAMRL, and subsequent measurements were compared with two existing LOs. This paper reports the comparison measurements as well as measurements of dark vergence obtained in the same subjects during the same sessions in which the optometer measurements were made. Dark vergence can be thought of as the intersection of the lines of sight of the two eyes in the dark. Although vergence and accommodation are highly correlated in a normally lighted environment, they go to different resting states in darkness (11). Dark vergence and its relationship to dark focus have been reported for samples of college students (12). Because the dark focus of the fighter pilots differed so dramatically from the dark focus of the college students, we hypothesized that a comparable difference between the subject samples would be found for dark vergence.

METHODS

SUBJECTS

Measurements were made on 17 male student naval aviators (SNAs) between the ages of 21 and 26 (mean age = 22.1 yrs). Although two subjects had glasses prescribed, they were not worn on a routine basis and were not used during data collection. The glasses did not exceed 0.5 D of correction.

APPARATUS

The LO is described in detail elsewhere (4,9) and illustrated in Fig. 1. The light source was a 1.0-mW helium neon laser (632.8 nm) with its beam diverged, passed through a shutter, and reflected from a front surface mirror onto an anodized aluminum drum rotating at 1.0 rpm. The drum surface reflected the beam through an iris, a +5.0-D lens, and onto a half-silvered mirror, which reflected the beam into the observer's eye. The eye was positioned at the focal plane of the Badal lens. A head-and-chin rest was used to stabilize eye position. The drum, front-surface mirror, shutter, and laser were all mounted on a carriage that could be moved along a slide toward or away from the Badal lens. A linear potentiometer was attached to the carriage, and a timing belt was attached to the unislide frame so that movement of the carriage turned the potentiometer. A digital display of the resistance change of the potentiometer was calibrated to be directly proportional to carriage position.

A photograph of the NAMRL VO prototype is shown in Fig. 2. The VO uses the Scheiner principle (13) illustrated in Fig. 3, in which S is a light source, O is a lens, and E and F are two pinholes between S and O. The pinholes isolate two bundles of rays, which come to a focus on the screen at N. When the screen is at N, a single image of S is on the screen. When the screen is closer to the lens, e.g., at M, then two images of S are formed on the screen; the upper one is from pinhole E, and the lower one is from pinhole F. When the screen is further from the lens, e.g., at L, then two images of S are again formed on the screen, but the lower image is from the upper pinhole E, and the upper image is from the

lower pinhole F. The plane at which only one image of S is formed on the screen is dependent upon the refractive power of lens O.

If the Scheiner principle is applied to the VO, lens O is the refractive media of the eye, and the screen is the retina. The two bundles of rays are isolated by light polarization as first suggested by Moses (10) and illustrated in Fig. 4. Two pairs of perpendicularly oriented polaroids are used. In Fig. 4, the two polarizers are placed next to each other in front of a horizontal bar of light. The two analyzers are placed in front of the pupil so that light entering the upper half of the pupil passes through one analyzer, and light entering the lower half of the pupil passes through the other analyzer. This arrangement causes the light through the upper and lower halves of the pupil to be polarized perpendicularly to each other. In the cases shown in the figure, light through the upper analyzer originates from the right half of the bar stimulus while light from the left half of the stimulus passes through the lower analyzer. When the eye is focused at the plane of the stimulus, a continuous bar is produced on the retina (A in Fig. 4). The polarization of the light on the left and right halves of the bar is different, but since the eye is not sensitive to this difference in polarization, the bar looks continuous. If the eye is focused short of the plane of the bar stimulus, then the incident light passing through the lower analyzer is higher on the retina than the incident light passing through the upper analyzer (B in Fig. 4). Conversely, when the eye is focused beyond the plane of the stimulus, then the light passing through the lower analyzer is lower on the retina than the light passing through the upper analyzer (C in Fig. 4).

Dark vergence was measured with a Maddox Rod centered with an adjustable trial lens holder in front of the left eye of the subject. The subject was presented with a circular white spot of light flashed in the dark for 500 ms using a UniBlitz shutter. The lamp housing and shutter were movable along a 25-ft optical bench. The seated subject looked down the length of the optical bench, which was centered and equidistant from both eyes.

PROCEDURES

The LO procedure is described in depth elsewhere (14,15). In brief, the distance of the rotating drum surface was found that produced an appearance of random motion when illuminated with the laser. The stimuli were presented as discrete trials, with the laser light presented as a 400-ms flash using a UniBlitz shutter.

The subject adjusted the VO by manipulating a toggle switch, which controlled the direction of the slide and stimulus display. When the subject was satisfied that the horizontal bar stimulus of polarized light appeared to be aligned or continuous, he put the toggle switch into the neutral position and pressed a button, which closed a shutter and signalled that the response was completed. The experimenter recorded the stimulus distance and put the slide at a predetermined random position for the next trial. Ten repeated measurements were made with the VO for each condition.

The procedure used to measure dark vergence was as follows: the stimulus was a small circular white light and appeared as such to the eye that did not have the Maddox rod in front of it. The white light viewed

through the Maddox rod appeared as a red vertical streak or ribbon with a width essentially the same as the diameter of the circular white light. The subject was instructed to report on which side of the ribbon the white light appeared: to the left, to the right, or centered on the ribbon. The experimenter moved the light source and shutter assembly toward or away from the subject to locate the distance at which the red ribbon and white light appeared to be superimposed. A bracketing strategy was used. Five such settings were recorded for each subject.

DESIGN

Each subject was tested in two identical sessions, which were designated as "test" and "retest." The sequence of tests for each session was 1) dark vergence, 2) VO with the room lights on, 3) VO with the room lights off, 4) first LO, and 5) second LO. All measurements made with the LOs were with the room lights off. To control for possible time of day effects that may affect dark focus, both sessions were scheduled for the same time of day for each subject; either at 0800 or 1300. Subjects were scheduled on Monday and Wednesday or Tuesday and Thursday, thereby permitting a 1-day interval between the test and retest sessions.

RESULTS

In Table 1, the means, standard deviations, and number of subjects from whom useful data were obtained are presented for each set of measurements as well as matched pair t-tests between the test and the retest means. None of the test and the retest means was significantly different from each other. Furthermore, the VO measurements obtained in the test or retest sessions in the light or the dark did not differ significantly among themselves, thus indicating that test results were reliable within instruments.

TABLE 1. Test and Retest Statistics.

Measure	Mean	SD	n	t-value	p
Dark vergence test	1.73 M	1.22 M	16	0.22	0.8295
Dark vergence retest	1.76 M	1.38 M	13		
VO light test	1.28 D	0.74 D	17	-0.13	0.9016
VO light retest	1.38 D	0.67 D	14		
VO dark test	1.39 D	0.88 D	17	1.08	0.3015
VO dark retest	1.40 D	0.59 D	14		
LO 1 test	-0.57 D	1.17 D	9	0.03	0.9745
LO 1 retest	-0.58 D	1.16 D	10		
LO 2 test	-1.51 D	1.09 D	15	-1.70	0.1279
LO 2 retest	-1.24 D	0.97 D	11		

M = Meters

D = Diopters

Comparisons among the optometers are far more complex. The LO 2 consistently measured a more myopic dark focus than the LO 1. The differences between LO 1 and LO 2 were evaluated with matched pair t-tests, some of which are summarized in Table 2. Only the initial testing of LO 1 and LO 2 were not statistically different from each other. All 16 possible matched pair t-test comparisons of the 4 VO means with the 4 LO means were significantly different beyond the 0.001 probability level. The results are consistent in showing that both LOs measure a more myopic dark focus than does the VO.

TABLE 2. T-tests and Probabilities for Test and Retest Comparisons Between Laser-Badal Optometers 1 and 2.

LO 1			
Test		Retest	
LO2	Test	$t = 1.34$ $\underline{p} = 0.2177$ $\underline{n} = 9$	$t = 6.07$ $\underline{p} = 0.0005$ $\underline{n} = 8$
	Retest	$t = 4.02$ $\underline{p} = 0.0051$ $\underline{n} = 8$	$t = 5.34$ $\underline{p} = 0.0001$ $\underline{n} = 10$

The correlation matrix among subject mean scores is shown in Table 3. The dark vergence test correlated with the dark vergence retest ($r = 0.71102$; $\underline{p} = 0.0064$) and with the LO 1 retest ($r = -0.83718$; $\underline{p} = 0.0049$). This correlation with LO 1 retest is probably fortuitous as we found no other evidence of a relationship between vergence and any other optometer measurement. All of the measurements with the VO in both the light and the dark correlated among themselves with high levels of significance.

The correlations were high between the LO 1 test and retest, the LO 2 test and retest, and the LO 1 and LO 2 retest. The correlation between the LO 1 and LO 2 tests was not statistically significant ($r = 0.28683$; $\underline{p} = 0.4543$).

The LO 1 test did not correlate significantly with the VO test in the light ($r = 0.61038$; $\underline{p} = 0.0809$) or in the dark ($r = 0.63034$; $\underline{p} = 0.0688$). It also did not correlate with the VO retest in the light ($r = 0.61450$; $\underline{p} = 0.1050$) but did correlate with the VO retest in the dark ($r = 0.86597$; $\underline{p} = 0.0055$). The LO 2 test did not correlate significantly with the VO test either in the light ($r = 0.42170$; $\underline{p} = 0.1174$) or in the dark ($r = 0.39699$; $\underline{p} = 0.1429$). The correlations among the LO and the VO retests were all statistically significant.

TABLE 3. A Correlation Matrix of the Means Reported in Table 1. The Correlation, the Probability, and the Number of Subjects are Listed.

Measure	A	B	C	D	E	F	G	H	I	J
Dark vergence test		0.71102 0.0064 13	-0.33218 0.2087 16	-0.23712 0.3415 13	-0.11044 0.5280 16	-0.30864 0.3049 13	-0.13220 0.7550 8	-0.33718 0.0049 9	-0.06818 0.8169 14	0.55020 0.0994 10
Dark vergence retest	B		-0.24722 0.4155 13	0.00370 0.9904 13	-0.28889 0.3384 13	-0.06514 0.8326 13	-0.00047 0.9992 7	-0.10862 0.7809 9	0.11586 0.7344 11	-0.02778 0.9393 10
VO light test	C			0.82581 0.0003 14	0.92622 0.0001 17	0.91119 0.0001 14	0.61038 0.0809 9	0.82597 0.0032 10	0.42170 0.1174 15	0.74676 0.0093 11
VO light retest	D				0.78506 0.0009 14	0.91197 0.0001 14	0.61450 0.1050 8	0.87434 0.0009 10	0.73682 0.0063 12	0.82983 0.0016 11
VO dark test	E					0.86958 0.0001 14	0.63034 0.0688 9	0.69666 0.0252 10	0.39699 0.1429 15	0.61603 0.0436 11
VO dark retest	F						0.86597 0.0055 8	0.89463 0.0005 10	0.68663 0.0137 12	0.79950 0.0031 11
L 01 test	G							0.91897 0.0013 8	0.28683 0.4545 9	0.79089 0.0194 8
L 01 retest	H								0.87832 0.0741 8	0.96182 0.0001 10
L 02 test	I									0.90647 0.0008 9
L 02 retest	J									

DISCUSSION

DARK VERGENCE

We hypothesized that the SNAs may have a different dark vergence than that reported for a college student sample and that the relationship between dark vergence and dark focus may be different for these two samples. Neither of these hypotheses was supported by the data. The average dark vergence of 1.16 m for college students (11) was not statistically different from the 1.73 or 1.76 m measured in the test or retest of the SNA. Furthermore, we did not find a significant correlation between the dark vergence test and retest and any optometer measurements, except for the dark vergence retest and the LO 1 retest, which we attribute to chance.

Dark vergence of fighter pilots may still be significantly different from that of college students, as fighter pilots are drawn from the SNA sample. The mean dark vergence of the SNA sample is about 0.6 m greater than that of the college students. Although this 0.6-m difference is not statistically significant, further factors of pilot selection or training could magnify this trend in experienced fighter pilots if, in fact, a far dark vergence is an advantage for pilot performance.

LASER OPTOMETER

Dark focus was significantly different from LO 1 and LO 2 tests and retests, although both instruments measured the same phenomena. This discrepancy can probably be attributed to physical differences between the two laser-Badal optometers. The size of the speckle pattern, as well as the size of the individual speckles, are larger in the LO 2 than in the LO 1. Both of these differences made it easier for the subjects to discriminate the motion in the speckle pattern with the LO 2 than with the LO 1. The greater difficulty with LO 1 was evident in several ways. For example, of the 17 subjects tested in the LO 1 tests, the results of only 9 were interpretable. The remaining eight subjects responded in an unsystematic fashion. With the LO 2, only two subjects responded in an unsystematic fashion. Consequently, the means of LO 1 are based on a smaller sample of subjects than the means of LO 2. With the LO 2, it was possible to measure the dark focus of six of the eight subjects who were not measurable with the LO 1 and the 9 who were. The LO 2 means of the six nonmeasurable subjects was 2.116 D of myopia while the LO 2 mean of the nine testable subjects was 1.115 D of myopia. This shows that the more myopic subjects were not testable on the LO 1 but were on the LO 2. The selective loss of the more myopic subjects resulted in a less myopic mean of dark focus with the LO 1 than the LO 2.

The results of the matched pair t-test between the LO 1 test and the LO 2 test were not statistically different ($t = 1.34$; $p = 0.2177$). Significant differences between the means of the LO 1 and LO 2 retests still remain to be explained.

We found no apparent differences between the LO 1 and the LO 2 other than the size of the speckles and the size of the pattern of speckles, which suggests that these must have caused the measured difference. Some clue may be found in the attitude of the subjects. In general, all of the

subjects and the data collection personnel expressed more personal dissatisfaction with the LO 1 than the LO 2. The four subjects who dropped out of the study had difficulty with the LO 1. The subjects who completed the measurements with both LOs required more stimulus presentations to obtain a threshold with the LO 1 than with the LO 2 (mean = 9.2, SD = 2.16 vs mean = 7.5, SD = 1.05). How these factors could affect the measurements is now impossible to evaluate; but, emotional stress and personality factors are known to affect dark focus measurements (15-17).

Because of significant differences between the two LOs, we emphasize that all of the measurements made on the U.S. Navy fighter pilots at Oceana, Virginia Beach, Virginia, and reported in the literature, utilized the LO 2 (14,15). This is the optometer that measured a more myopic dark focus than the LO 1 in the SNA sample. The amount of dark focus myopia measured with the LO 2 was in the range reported in the literature and is comparable with the general population and Air Force recruits (2,3,8). This observation is important since it is consistent with the conclusion that Navy fighter pilots have remarkably little myopia in the dark (13,14). Furthermore, this observation is consistent with the suggestion that the subject difficulties experienced with the LO 1 interacted with personality factors to produce the observed differences between the two LOs.

VERNIER OPTOMETER

The test-retest reliability of the VO, both in the light and in the dark was about 0.85, and the mean scores differed by no more than 0.25 D. Thus the VO seems to be a reliable instrument.

The VO measurements made in the light were not significantly different from those made in the dark. This is an important practical consideration in test administration and suggests that special room lighting may not be necessary to evaluate dark focus made with the VO. This would greatly simplify test administration.

COMPARISON OF VERNIER AND LASER OPTOMETERS

All of the subjects produced reliable and consistent responses on the VO; this was not the case with either of the LOs. Subject acceptance of the VO was clearly much better than either LO. On the average, less than 5 min were needed to make 10 repeated measurements with the VO while 20 min were required to make 6 repeated measurements with the easier of the two LOs, LO 1. Measurements made with the VO and the room lights on or off, were not significantly different. This would suggest that special lighting conditions were not required to obtain measurements with the VO. In every way, the VO was an easier instrument to use than either of the two LOs.

The differences between the two types of optometers are difficult to evaluate and explain. The means of the VO in all conditions are consistent but about 2.0 D less myopic than the LO measurements, as well as the means reported in the literature. The fact that the differences were constant suggested that a calibration error had been made. A thorough investigation proved otherwise, but we did identify a number of shortcomings in the current VO. For example, plano-convex lenses with large off-axis aberrations were used as well as an inadequate head stabilization procedure and a poorly designed test target. All of these factors could have contributed

to an increased variability in response, but they do not necessarily account for differences between the observed and expected VO measurements.

The origin of the differences between the LOs and the VO remains a problem that should be solved. As a first step in that direction, a new VO should be constructed with better head stabilization, biconvex lenses with minimal optical aberration, and a better stimulus target. If the discrepancy between the LO and the VO can be resolved, the VO promises to be a useful screening tool because it is easy to use, inexpensive to produce, and does not require special lighting conditions.

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LASER-BADAL OPTOMETER

- A-MOTOR DRIVE FOR FOCUSING
- B-LASER
- C-ELECTRIC SHUTTER
- D-MOTOR DRIVE FOR DRUM
- E-MIRROR
- F-ROTATING CYLINDER
- G-BADAL LENS
- H-BEAMSPLITTER
- I-IRIS & FILTER COMBINATION

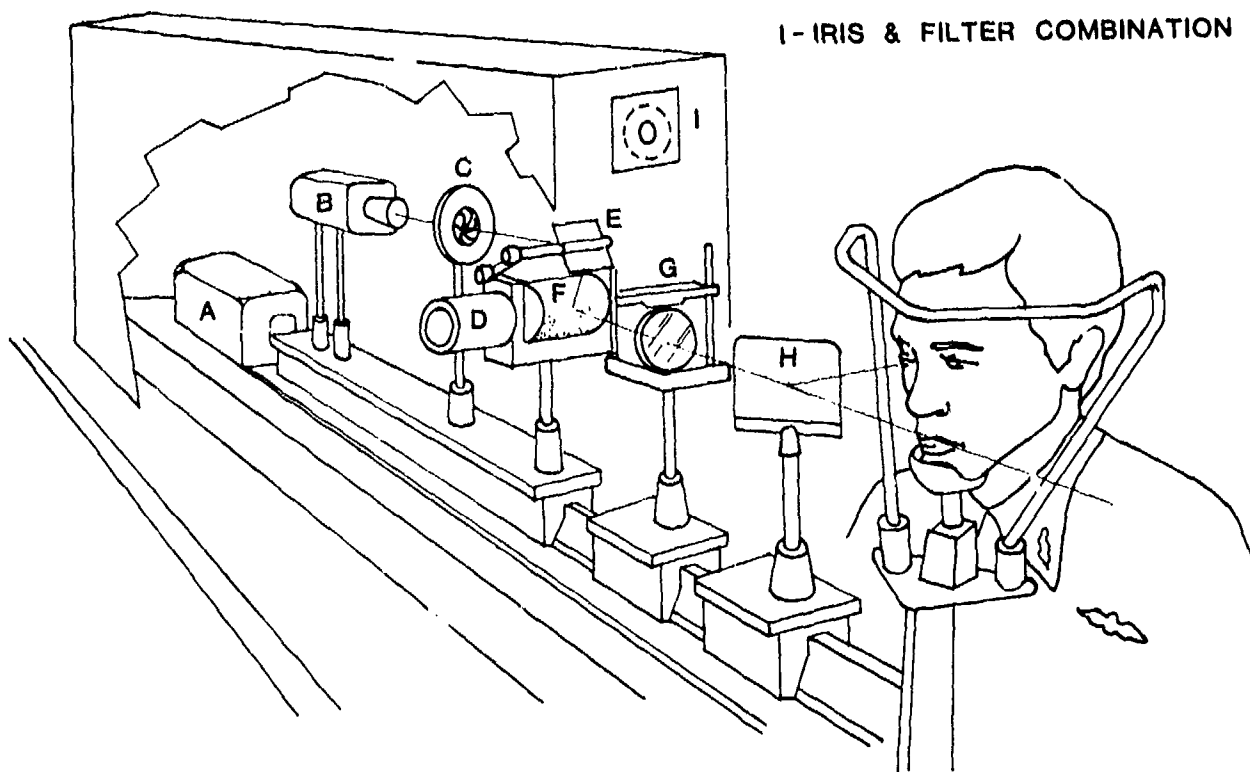


Figure 1. The laser-Badal optometer.

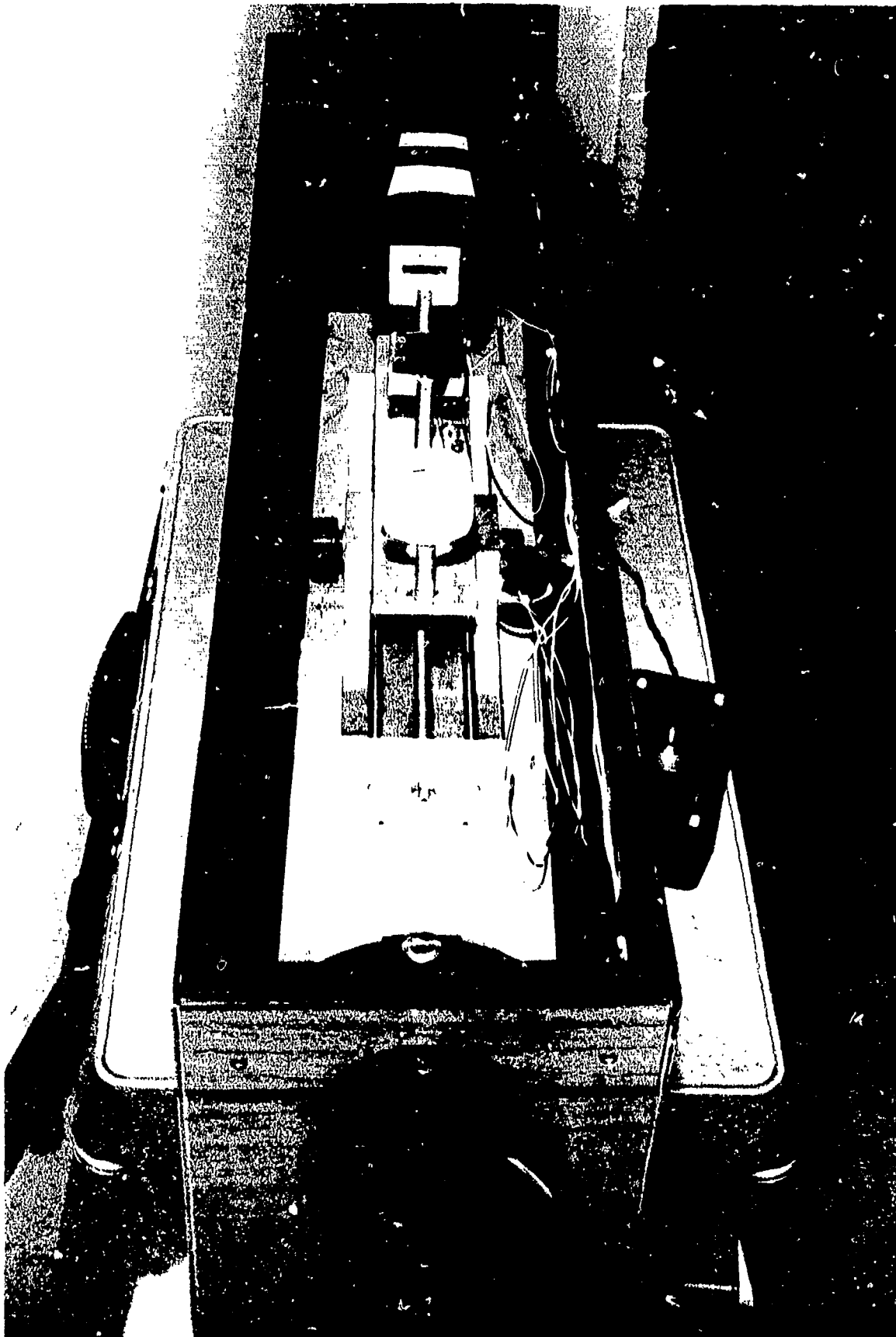


Figure 2. The NAMRL vernier optometer.

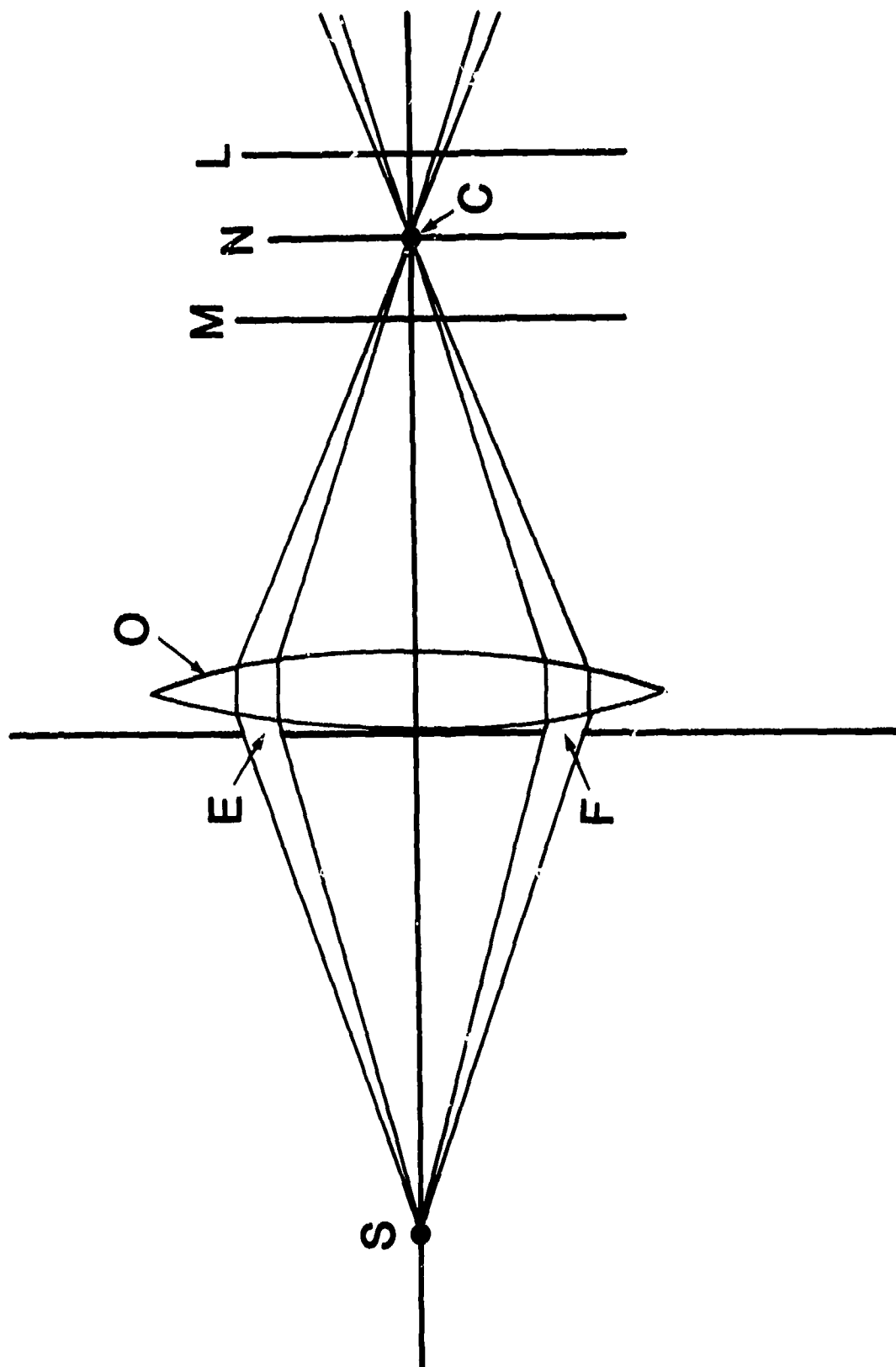


Figure 4. The principle of the vernier optometer (after Moses).

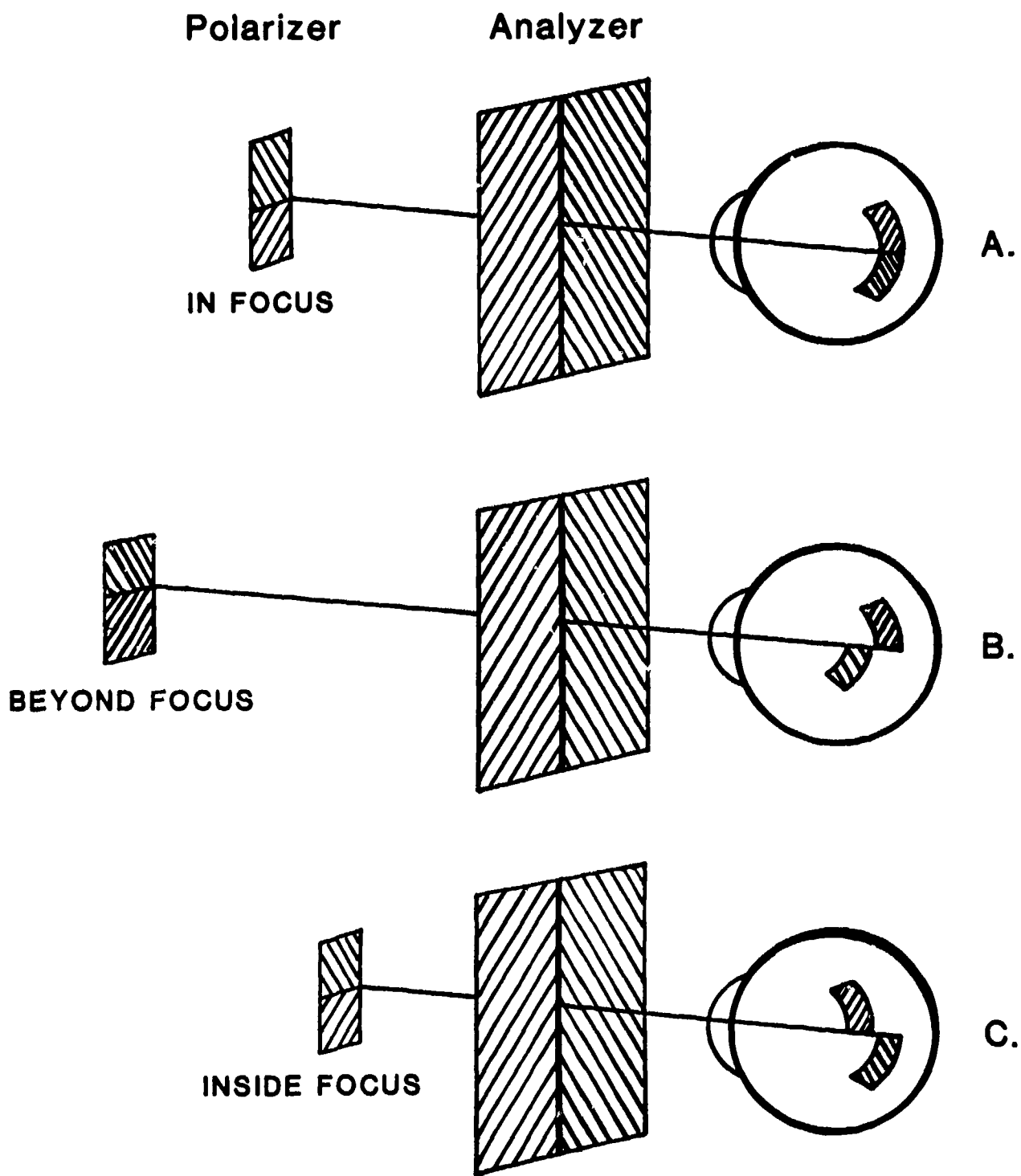


Figure 3. The Scheiner principle (after von Helmholtz, page 126).

OTHER RELATED NAMRL PUBLICATIONS

Temme, L. A. and Ricks, E., Accommodative Status in the Dark of J.S. Fighter Pilots. NAMRL-1332, Naval Aerospace Medical Research Laboratory, Pensacola, FL, March 1987.

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